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IV. *A Contrivance to avoid the Irregularities in a Clock's Motion, occasion'd by the Action of Heat and Cold upon the Rod of the Pendulum. By Mr. George Graham, Watch-Maker, F. R. S.*

**W**Hereas several, who have been curious in measuring of Time, have taken Notice, that the Vibrations of a Pendulum are slower in Summer than in Winter; and have very justly supposed this Alteration has proceeded from a Change of Length in the Pendulum itself, by the Influences of Heat and Cold upon it, in the different Seasons of the Year; with a View therefore of correcting, in some degree, this Defect of the Pendulum, I made several Trials, about the Year 1715. to discover whether there was any considerable Difference of Expansion between Brass, Steel, Iron, Copper, Silver, &c. when exposed to the same Degrees of Heat, as nearly as I could determine; conceiving it would not be very difficult, by making use of two Sorts of Metals, differing considerably in their Degrees of Expansion and Contraction, to remedy, in great measure, the Irregularities to which common Pendulums are subject. But altho' it is easily discoverable, that all these Metals suffer a sensible Alteration of their Dimensions by Heat and Cold; yet I found their Differences, in Quantity from one another, were so small, as gave me no Hopes of succeeding this Way, and made me leave off prosecuting this Affair any farther at that Time. In the Beginning of December, 1721. having Occasion for an exact Level, besides other Materials I made Trial of, Quicksilver was one; which, although I found it was by no Means proper for a Level, yet the extraordinary Degree

gree of Expansion, that I observed in it, when placed near the Fire, beyond what I had conceived to be in so dense a Fluid, immediately suggested to me the Use that might be made of it, by applying it to a Pendulum. In a few Days after, I made the Experiment, but with much too long a Column of Quicksilver the Clock going slower with an increase of Cold, contrary to the common Pendulum ; however, it was a greater Confirmation of the Advantage to be expected from it, since it was easy to shorten the Column in any Degree required. The only Doubt I entertained, was, lest there should not be a proportional Expansion and Contraction between the Quicksilver, and the Rod of the Pendulum, through the various Degrees of Heat and Cold, from the one Extreme to the other. To make this Experiment the more convincing, I placed the Clock in a Part of the House, the most exposed of any to the Changes of Heat and Cold, the Room having no Fire in it in the Winter, and exposed to a South Sun, with Leads above it, which, in the Summer, made it extremely hot. I hung a Thermometer by it, and had likewise another Clock at no greater Distance from it, than was necessary to keep the Cases from touching one another. This Clock had been made some Years before, with extraordinary Care, having a Pendulum about 60 Pounds in Weight, and not vibrating above one Degree and half from the Perpendicular ; and which, in a more temperate Situation, had not alter'd above 12 or 14'' in 24 Hours, between Winter and Summer ; but in this Place it altered 30'' a Day, between the hottest and coldest Weather, in the Year 1722, a Year no way remarkable for either Extremes. But this great Alteration was owing to the Situation I mentioned above, and which I made Choice of for the sake of making the Experiment the more sensible.

The two Clocks being firmly skrewed to a Party-Wall, I began to make the first Trial of this Kind of Pendulum, *December* 18. 1721. and by *January* the third, perceiving the Pillar of Quicksilver considerably too long, I procured a shorter Glass, which I got ready by the eighth, and made use of, until the Beginning of *June* following: By which Time I was well satisfied of the Advantage of the Contrivance, notwithstanding both these Pendulums were but rudely executed, and this last had the Pillar of Quicksilver too short, but much nearer the true Length than the first. This encouraged me to provide another Glass, a little longer than the last, and to bestow more Care upon all the Parts of the Pendulum that required Exactness. This being finished, by the 9th of *June*, I began then to observe the Motion of the Clock, by the Transits of the fixed Stars, as often as the Weather permitted, making use of a Telescope which moved in the Plane of the Meridian; with this Instrument I could be sure of not erring above two Seconds in Time. The Clock was kept constantly going, without having either the Hands or Pendulum alter'd, from the 9th of *June*, 1722. to the 14th of *October*, 1725. being three Years and four Months.

For the first Year, I wrote down every Day, the Difference between the two Clocks, with the Height of the Thermometer, not omitting the Transits of the Stars, as often as it was clear. The Result of all the Observations was this, That the Irregularity of the Clock, with the Quicksilver Pendulum, compared with the Transits of the Stars, exceeded not, when greatest, a sixth Part of that of the other Clock with the common Pendulum; but for the greatest Part of the Year, not above an eighth or ninth Part; and even this Quantity would have been lessened, had the Pillar of

Mercury been a little shorter; for it differed a little the contrary Way from the other Clock, going faster with Heat, and slower with Cold; but I made no Alteration in the Length, to avoid an Interruption of the Observations. To confirm this Experiment the more, about the Beginning of *July*, 1723, I took off the heavy Pendulum from the other Clock, and made another with Quicksilver, but with this Difference, that instead of a Glass Tube, I made use of Brass, and varnished the inside, to secure it from being injured by the Mercury. This Pendulum I have made use of ever since, and find it about the same Degree of Exactness as the other. The Reason, why this kind of Pendulum is more exact than the common Sort, will be evident to any one, who considers, that as Heat lengthens the Rod of the Pendulum, at the same Time it increases the Length of the Pillar of Quicksilver, and its Center of Gravity is moved upwards: And when by Cold, the Rod of the Pendulum is shortened, the Pillar of Quicksilver is likewise shortened, and its Center of Gravity carried downwards; by this Means, if the Column of Quicksilver be of a proper Length, the Distance, between the Point of Suspension and the Center of Oscillation of the Pendulum, will be always nearly the same upon which the exact Motion of a Clock principally depends. Were the Pendulum of a Clock to remain invariably of the same Length, yet some little Inequalities would appear in its Motion, from the Difference of Friction arising from the Imperfections of the Materials, as well as different Degrees of Foulness; upon which Account, the Force communicated to the Pendulum, would not be constantly equal, which would cause some small Alteration. But when the Pendulum is very heavy, and vibrates in a small Arch, and the Workmanship of all the Parts is well per-

formed, there will be very little Inequality in the Motion, besides what proceeds from Heat and Cold.

In making use of Quicksilver for a Pendulum, by varying the Diameter of the Vessel that contains it, or the Thickness of the Rod of the Pendulum, whether it be of Brass or Steel, they may be reduced nearly to an Equality as to the receiving, or retaining the Impressions of Heat or Cold, upon which the greater Regularity of the Motion depends; and particular Care ought to be used to free the Mercury from all Blebs of Air, otherwise their great and sudden Expansion, or Contraction, may cause a considerable Disorder; but the Air may as easily be excluded in this Way, as in a Barometer, and the great specifick Gravity of Quicksilver, renders it a proper Material for the Weight of a Pendulum.

F I N I S.